

LCA Case Studies

Life Cycle Assessment of a Pyrolysis/Gasification Plant for Hazardous Paint Waste

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Abstract

Goal, Scope and Background. Life Cycle Assessment (LCA) remains an important tool in Dutch waste management policies. In 2002 the new National Waste Management Plan 2002–2012 (NWMP) became effective. It was supported by some 150 LCA studies for more than 20 different waste streams. The LCA results provided a benchmark level for new waste management technologies. Although not new, operational techniques using combined pyrolysis/gasification are still fairly rare in Europe. The goal of this study is to determine the environmental performance of the only full scale pyrolysis/gasification plant in the Netherlands and to compare it with more conventional techniques such as incineration. The results of the study support the process of obtaining environmental permits.

Methods. In this study we used an impact assessment method based on the guidelines described by the Centre of Environmental Science (CML) of Leiden University. The functional unit is defined as treatment of 1 ton of collected hazardous waste (paint packaging waste). Similar to the NWMP, not only normalized scores are presented but also 7 aggregated scores. All interventions from the foreground process (land use, emissions, final waste) are derived directly from the site with the exception of emissions to soil which were calculated. Interventions are accounted to each of the different waste streams by physical relations. Data from background processes are taken from the IVAM LCA database 4.0 mostly originating from the Swiss ETH96 database and adapted to the Dutch situation. Allocation was avoided by using system enlargement. The study has been peer reviewed by an external expert.

Results and Discussion. It was possible to determine an environmental performance for the pyrolysis/gasification of paint packaging waste. The Life Cycle Inventory was mainly hampered by the uncertainty occurred with estimated air emissions. Here several assumptions had to be made because several waste inputs and two waste treatment installations profit from one flue gas cleaning treatment thus making it difficult to allocate the emission values from the flue gasses.

Compared to incineration in a rotary kiln, pyrolysis/gasification of hazardous waste showed better scores for most of the considered impact categories. Only for the impact categories biodiversity and life support the incineration option proved favorable due to a lower land use.

Several impact categories had significant influence on the conclusions: acidification, global warming potential, human toxic-

ity and terrestrial ecotoxicity. The first three are related to a better energy efficiency for pyrolysis/gasification leading to less fossil energy consumption. Terrestrial ecotoxicity in this case is related to specific emissions of mercury and chromium (III).

A sensitivity analysis has been performed as well. It was found that the environmental performance of the gasification technique is sensitive to the energy efficiency that can be reached as well as the choice for the avoided fossil energy source. In this study a conservative choice for diesel oil was made whereas a choice for heavy or light fuel oil would further improve the environmental profile.

Conclusions. Gasification of hazardous waste has a better environmental performance compared to the traditional incineration in rotary kilns mainly due to the high energy efficiency. As was determined by sensitivity analysis the differences in environmental performance are significant. Improvement options for a better performance are a decrease of process emissions (especially mercury) and a further improvement of the energy balance by decreasing the electricity consumption for shredders and oxygen consumption or making more use of green electricity.

Recommendations and Perspectives. Although the life cycle inventory was sufficiently complete, still some assumptions had to be made in order to establish sound mass balances on the level of individual components and substances. The data on input of waste and output of emissions and final waste were not compatible. It was recommended that companies put more emphasis on data storage accounted to particular waste streams. This is even more relevant since more companies in the future are expected to include life cycle impacts in their environmental performance.

Keywords: Avoided burden; hazardous waste; life cycle assessment; paint waste; pyrolysis/gasification; waste management

1 Background of the Study

In March 2003 the Dutch National Waste Management Plan (NWMP) became effective. Preparing the NWMP was mandatory as a result of the Environmental Management Act. The NWMP elaborates on the policy view on waste management in the forthcoming years. The NWMP has five important objectives:

1. Stimulate prevention in such a way that decoupling of waste generation and the GDP is enhanced;
2. Stimulate re-use (from 77% in 2002 to 83% in 2012) of waste especially through source separation
3. Make optimal use of caloric value of waste (waste-to-energy) in case re-use is not an option;

4. Maintain the amount of waste for final disposal by land filling and incineration to approx. 9,5 Mton in 2012 despite growth of waste supply by some 16% compared to the year 2000;
5. Create an European level play field, enhance market opportunities and stimulate innovative prevention and waste management options.

In order to keep waste management up to the highest possible standards, the NWMP also sets minimum standards for the processing of all the waste streams. The minimum standards relate to the processing and handling of particular wastes or categories of wastes and are intended to prevent wastes being handled or processed in ways, which are not up to the desired standard. The standards are therefore an elaboration of the order of preference for individual wastes and are formulated as much as possible as targets. They therefore act as benchmarks for permit procedures.

This approach was already used in an earlier policy plan, namely the National Hazardous Waste and Management Plan 1997–2007, and extensively elaborated in a series of articles in the International Journal of Life Cycle Assessment [1–3].

As a prelude to their environmental permit procedure, ATM¹ commissioned IVAM to conduct a LCA for their pyrolysis/gasification installation since this was not mentioned as a waste management option in the NWMP [4]. A shredder/flush process of ATM was mentioned in the NWMP but is not operational any longer. The pyrolysis/gasification process was compared with the treatment in a rotary kiln which was defined as the minimum standard for this type of waste.

2 Choice of the Functional Unit, Relevant Technologies and Data Inventory

In the comparison the functional unit is defined as 1 ton of average paint waste. Data was given by ATM in their application for environmental permits. Paint waste contains some 16% metal, 41% organic material, 34% inert material and 9% water. Paint waste consists of large bins with refuse of paint but also paint sludges, paint powders, glue, used brushes, used cloth, etc. This type of waste is considered different from paint packaging waste. The latter consists of used small bins and cans which are partly empty and partly contain paint sludges.

A physical input-output calculation was used to establish a mass balance on substance level. The composition of residues and the emissions to water and air were measured, emissions to soil were calculated. This enabled us to determine the composition of paint waste on substance level (Table 1). For the sake of completeness the composition of paint packaging waste is mentioned as well.

As mentioned above, the considered technologies were a pyrolysis/gasification and a rotary kiln process.

Background processes were taken from the database of IVAM [5]. The majority of the applied processes stem from the ETH96-database [6] some of which are adapted to the Dutch situation.

¹ ATM (*Afval Terminal Moerdijk*) is part of Shanks Netherlands bv

Table 1: Composition of paint waste and paint packaging waste

Component	Unit	Paint waste	Paint packaging waste
Dry Matter	%	91	94
Ash	%	34	26
Hydrocarbons	%	41	48
Metal	%	16	20
Caloric value	MJ/kg	16,3	20.6
As	mg/kg dm	17	11
Cd	mg/kg dm	26	18
Co	mg/kg dm	116	77
Cr	mg/kg dm	206	137
Cu	mg/kg dm	1,281	854
Hg	mg/kg dm	2.8	1.6
Mo	mg/kg dm	118	78
Ni	mg/kg dm	19	12
Pb	mg/kg dm	2,385	1,590
Sb	mg/kg dm	63	42
Tl	mg/kg dm	0.5	0.5
Zn	mg/kg dm	5,310	3,540
Cl	mg/kg dm	759	392
S	mg/kg dm	1,430	739

Both the inventory and impact assessment in this study were subjected to a peer review.

2.1 Pyrolysis/gasification

Both gasification and pyrolysis are considered as major opportunities for recovering material and energy value from waste. Especially since legislative drivers in the EU aim at decreased landfill activities and increased material recovery and/or recovery of energy, gasification and pyrolysis are (again) in focus as an alternative to incineration. However doubts about the less proved technology and unclear economic benefits hamper a larger market penetration. The advantages of gasification and pyrolysis for greater flexibility in terms of energy production and material recycling remain evident [7].

Intermezzo: What are gasification and pyrolysis [7]?

Both gasification and pyrolysis convert wastes into energy-rich fuels by heating the waste under controlled conditions. Whereas incineration completely transforms the input waste into energy and ash, gasification and pyrolysis deliberately limit the conversion so that combustion does not take place directly. Instead, they convert the waste into valuable intermediates that can be further processed for materials recycling and energy recovery. Gasification is a partial oxidation process in which the majority of the carbon is converted into the gaseous form, called syngas, by partial combustion of a portion of the fuel in the reactor with air, pure oxygen, oxygen-enriched air or by reaction with steam. Relatively high temperatures are employed: 900–1100°C with air and 1000–1400°C with oxygen. Air gasification is the most widely used technology, but it results in a relatively low energy gas containing up to 60% nitrogen and with a heating value of 4–6 MJ/m³. Oxygen gasification gives a better quality of gas with a heating value of 10–18 MJ/m³, but the need for an oxygen supply has capital and operating cost implications.

Pyrolysis is the thermal degradation of carbonaceous materials. It occurs at lower temperatures than gasification (typically 400–800°C), either in the complete absence of oxygen, or with such a limited supply that gasification does not occur to any appreciable extent. Such processes devolatilize and decompose solid (organic) materials by heat. The products of pyrolysis include gas, liquid and solid char. Their relative proportions depend on the method of pyrolysis and reaction parameters such as temperature, pressure and residence time. Lower temperatures produce more liquid product and high temperatures produce mostly syngas. However, subsequent processing can convert one to the other.

Several technologies claiming to be gasification, pyrolysis or combination of those since the definition is open to interpretation. In some cases processes using gasification incorporate pyrolysis as the initial stage of the reaction process. This is the case for the ATM installation as well.

The pyrolysis/gasification plant of ATM has an annual capacity of 60,000 tonnes. Currently some 28,000 tonnes of paint waste are processed next to 6,000 tonnes of paint packaging waste and 26,000 tonnes of oil containing sludges from various sources. The plant is operational since 1998 and, after some years with severe technological problems and subsequent additional modifications, currently fully operational. It is one of the few installations in (Western-)Europe of this type and with this capacity.

For all waste types data on contents of impurities and the caloric value were retrieved. In the case of energy for instance the mass fraction and the caloric content of each waste type was used to calculate the total energy input. The share of the paint waste is extrapolated to the output of energy (and therewith the avoided burden) implying that the energy conversion efficiency for all three waste types is identical.

Before entry in the pyrolysis/gasification installation, the paint waste is treated in a shredder to reduce the particle size (Fig. 1). After the shredder the paint waste is mixed

with other waste streams and transported into the pyrolysis/gasification. The waste is heated to a maximum temperature of $\pm 600^\circ\text{C}$. On the input side of the reactor a small amount of pure oxygen is added. The temperature of the gasses here is between 900 and 1,200°C. This temperature is also maintained due to the slight angle in which the reactor is placed causing an upward transport of heated syngas. On the output side of the reactor no oxygen is added thus leading to slightly lower temperatures. The process is auto-thermal. Natural gas is only added in the start up phase.

The solid residues from the reactor are transported to another compartment for full oxidation of organic matter by adding pure oxygen. Dutch environmental landfill decrees require a maximum organic matter content of 5% in final waste residues. The residues are de-ironed and cooled before temporary storage. Recovered metals are re-used as auxiliary materials in primary steel industries. Final disposal of residues takes place in landfill sites since the leaching behavior does not meet the environmental standards from the Building Materials Decree. Therefore the re-use as secondary building material is prohibited.

The syngas is cooled and washed to remove carbon particles and other small particles. The gas then is transported to a nearby facility for the thermal treatment of contaminated soil. Energy available in the syngas (approx. 6,8 MJ/m³) is converted into heat thus replacing fossil fuels with the same function (avoided burden). The avoided burden was dictated by the caloric value of the waste, the efficiency of the gasification and the efficiency of the machines that utilize the syngas. A conservative choice was made for the substitution of diesel oil whereas the substitution of light fuel oil might also be a plausible option.

The flue gasses from the syngas are treated with other flue gasses that arise in the neighbouring thermal treatment facility for contaminated soil. Flue gas cleaning con-

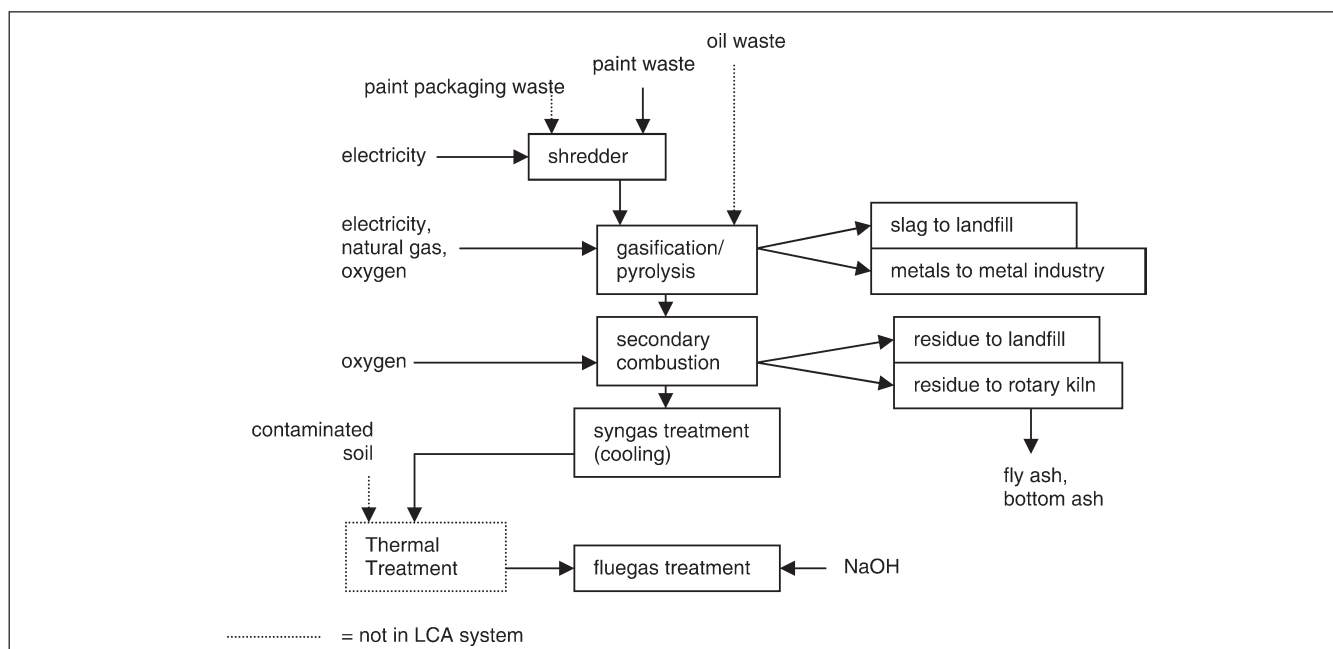


Fig. 1: Overview of pyrolysis/gasification process in LCA

Table 2: Input data for the treatment of 1 ton of paint waste in pyrolysis/gasification plant

Inflow	Per ton paint waste	Outflow	Per ton paint waste
Transport: waste in	75 tkm	Transport: residues out	27 tkm
Transport: oxygen in	2.4 tkm	Transport: metals out	24 tkm
Auxiliary materials: sodiumhydroxy (20%)	11.3 kg	Energy: syngas out	11.800 MJ
Auxiliary materials: oxygen	470 kg	Materials: metals to blast furnace	160 kg
Energy: grid electricity in	430 MJe	Final waste	424 kg ^a
Energy: natural gas in	1.67 m ³		
Energy: landfill	24 MJmech		
Land use: pyrolysis/gasification site	0.1 m ² .yr		
Land use: landfill residues	2.97 m ² .yr		

^a Including 20–25% water

sists of electrostatic dust filters and wet scrubbing with an alkali solution.

The offset of ferrous metals was taken into account as these metals from the gasification plant are transported to a blast oven furnace (BOF). The offset was applied to process of resource extraction until the production of pig iron. It was assumed that the energy demand from there on is similar for both primary material as secondary ferrous metals and therefore this offset is not accounted for.

In **Table 2**, the most relevant input data for the treatment of 1 ton of paint waste in pyrolysis/gasification plant are presented.

The syngas yield is calculated at 1,008 kg per ton of paint waste. The total energy efficiency of the plant is calculated at 70.3%. The energy consumption for producing oxygen was not accounted for in this efficiency. In the LCA however all energy consuming processes were taken into account including the production of oxygen.

In an earlier testing phase in 2000–2001 data of the composition of syngas has been obtained. Some measurements on the efficiency of the flue gas cleaning were also available. Making a sound mass balance over the several inputs and outputs of the flue gas cleaning at the treatment facility for contaminated soil proved the most difficult task in this study and several assumptions had to be made here. Conservative estimations for the amount of heavy metals present in flue gasses were made ranging from a volatilization of 10% for most heavy metals to 40% for mercury. Considering the fact that most metals, if present, will condensate while cooling the syngas makes it plausible that air emissions were somewhat overestimated.

The composition and leaching of residues has also been determined. Leaching data obtained with standardized tests are necessary to assess the suitability of residues for secondary materials. In this case however the quality of the residues is not sufficient for re-use and therefore a disposal on a landfill is needed. The leaching data were used to calculate emissions from the landfill site. Data on the composition of the residues were used to determine the fate of substances after treatment in rotary kilns since a percentage of the residues is treated there as not all residues meet the quality standards for disposal in landfills. Subsequent energy use and production in the rotary kiln from these residues were neglected because of the low caloric value of the residues.

Emissions to water accountable to the paint waste do not occur at the pyrolysis/gasification site.

With the data mentioned above a mass balance of all substances was established for the pyrolysis/gasification plant. However uncertainties in this balance remain mainly due to ever changing compositions of the waste.

Table 3 gives an overview of accounted emissions to several environmental compartments from the gasification plant (not the entire life cycle!). Note that emissions of NO_x, CO, C_xH_y, dust, dioxins were not measured but calculated with emission values per MJ of caloric input value as used in the NWMP.

2.2 Rotary kiln

The rotary kiln is a well-known incineration process. Until the end of 2004 one plant with two kilns was operational in the Netherlands. Since early 2005 these activities have been stopped.

Paint waste is mixed with other high caloric waste streams before it enters the reactor. The rotary kiln is a cylinder shaped reactor with a rotation speed of 5–15 rotations per hour. A final incineration takes place in the secondary combustion chamber of the reactor. Residence time of the gasses is minimal 2 seconds at temperatures of 1,000–1,200°C. Flue gasses are cooled under production of high and middle pressure steam. Steam is then converted in a nearby facility into electricity for the grid and also used for the production of distilled water. System enlargement here was used by substituting the Dutch national mix of fuel dominated by gas and coal for the production of electricity and distilled water (avoided burden). Also here the avoided burden was dictated by the caloric value of the waste and the efficiency of the incineration.

After incineration an air pollution control takes place consisting of an electrostatic dust filters and wet scrubbing but here also an active coal filter is in place. All residues from the rotary kiln (fly ash, bottom ash and flue gas residue) are disposed of in controlled landfill sites, partly after immobilization with cement. **Table 4** presents the most relevant input data for the treatment of 1 ton of paint waste in a rotary kiln.

Table 3: Emissions to air, water, soil (in mg) per ton treated paint waste from a pyrolysis/gasification plant

Substance	Source	Emissions to Air	Emissions to Water	Emissions to Soil
As	Pyrolysis/gasification	0.21	0	47.4
Ba	Pyrolysis/gasification	33.3	0	32.0
Cd	Pyrolysis/gasification	0.45	0	10.3
Co	Pyrolysis/gasification	0.54	0	126
Cr	Pyrolysis/gasification	1.97	0	12.9
Cu	Pyrolysis/gasification	121.2	0	174
Hg	Pyrolysis/gasification	3.86	0	0
Ni	Pyrolysis/gasification	0.22	0	29.0
Pb	Pyrolysis/gasification	2.03	0	47.7
Sb	Pyrolysis/gasification	0.46	0	14.2
Se	Pyrolysis/gasification	6.52	0	0
Sn	Pyrolysis/gasification	0.95	0	2.60
V	Pyrolysis/gasification	0.57	0	17.1
HCl	Pyrolysis/gasification	7.542	? (Cl ⁻)	4.3 E5 (Cl ⁻)
HF	Pyrolysis/gasification	78.9	? (F ⁻)	? (F ⁻)
SO ₂	Pyrolysis/gasification	9,285	? (SO ₄)	3.4 E5 (SO ₄)
NO _x	Pyrolysis/gasification	148,859	n.a.	n.a.
CO	Pyrolysis/gasification	24,522	n.a.	n.a.
CO ₂	Pyrolysis/gasification	1,086*E9	n.a.	n.a.
CxHy	Pyrolysis/gasification	879	n.a.	n.a.
Dioxins	Pyrolysis/gasification	4.63*E-5	n.a.	n.a.
dust (PM10)	Pyrolysis/gasification	2,899	n.a.	n.a.
As	Rotary kiln ^a	1.55	0.5	0.6
Ba	Rotary kiln ^a	108.3	30.5	84.0
Cd	Rotary kiln ^a	49.7	45.6	1.8
Co	Rotary kiln ^a	11.0	3.1	4.2
Cr	Rotary kiln ^a	20.4	5.8	138.5
Cu	Rotary kiln ^a	121.8	34.3	46.3
Hg	Rotary kiln ^a	23.4	5.1	0.0
Mo	Rotary kiln ^a	11.1	3.2	71.0
Ni	Rotary kiln ^a	1.77	0.5	2.4
Pb	Rotary kiln ^a	226.6	63.8	86.0
Sb	Rotary kiln ^a	6.02	1.7	6.8
Se	Rotary kiln ^a	0.52	0.2	0.2
Sn	Rotary kiln ^a	7.73	2.2	2.9
V	Rotary kiln ^a	25.8	?	?
Zn	Rotary kiln ^a	505.2	142.2	191.5

^a Emissions due to treatment of gasification residues in rotary kiln**Table 4:** Input data for the treatment of 1 ton of paint waste in rotary kiln

Inflow	Per ton paint waste	Outflow	Per ton paint waste
Transport: waste in	150 tkm	Transport: residues out	29 tkm
Auxiliary materials: active carbon	19.3 kg	Energy: grid electricity out	1,733 MJ
Auxiliary materials: cement	8.5 kg	Others: distilled water out	6.6 ton
Auxiliary materials: other	2.1 kg	Final waste	370 kg
Energy: grid electricity in	790 MJ		
Energy: immobilization and landfill	23 MJmech		
Land use: rotary kiln site	0.4 m ² .yr		
Land use: landfill residues	2.9 m ² .yr		

Table 5: Emissions to air, water, soil (in mg) per ton treated paint waste from a rotary kiln

Substance	Emissions to Air	Emissions to Water	Emissions to Soil
As	10.8	0.009	10.4
Cd	178	0.50	19.5
Co	73.9	0.063	68.7
Cr	131	0.113	1,854
Cu	816	0.70	747
Hg	76.4	0.051	1.3
Mo	75.2	0.064	1,253
Ni	12.1	0.01	36.2
Pb	1,519	1.30	1,391
Sb	40.1	?	97.7
Zn	3,382	2,9	3,098
HCl	207	? (Cl)	? (Cl)
HF	0	? (F)	? (F)
SO ₂	11,712	767 (SO ₄)	26,652 (SO ₄)
NO _x	1,956,000	n.a.	n.a.
CO	196,000	n.a.	n.a.
CO ₂	1,140 E6	n.a.	n.a.
CxHy	48,900	n.a.	n.a.
Dioxins	4.89E-10	n.a.	n.a.
Dust (PM10)	35,700	n.a.	n.a.

Mass balances for the rotary kiln were taken from the NWMP to determine the amount of residues (bottom ash, fly ash, flue gas residue) produced as well as to determine the allocation of substances over these materials. Emissions were derived from historical data on the emission behavior of substances in the rotary kiln. **Table 5** gives an overview (again not the entire life cycle).

3 Impact Assessment

For the impact assessment, the CMLII guide was followed [8]. In contrast with earlier LCA's, for waste management, terrestrial ecotoxicity was added as a LCA theme (**Table 6**).

There was sufficient confidence in the determination of leaching from either secondary materials in their application or final waste in landfills to include these interventions. The time scale for both options however was different. The leaching from secondary materials in their application was cut off at 100 years in accordance with the Building Material Decree. The rationale for this is the fact that application usually has a life span of a maximum 100 years and often even shorter. Second cascade leaching and further was not accounted to the waste treatment option. For leaching from landfill a time horizon of 10,000 years was chosen, in accordance with common deliberations (in the Netherlands) on the life span of landfill sites.

Table 6: LCA-themes in impact assessment

Adopted LCA themes	Acronym	Unit	Normalization factor Netherlands 1997
Abiotic depletion	AD	kg Sb-equivalents	1.65E+9
Global warming (100 years)	GWP	kg CO ₂ -equivalents	2.51 E+11
Ozone layer depletion	ODP	kg CFK-equivalents	9.77 E+5
Photo-oxidant formation	POCP	kg C ₂ H ₂ -equivalents	1.82E+8
Aquatic ecotoxicity (fresh water)	AETP	kg 1,4-DCB-equivalents	7.54E+9
Terrestrial ecotoxicity	TETP	kg 1,4-DCB-equivalents	9.59E+8
Human toxicity	HTP	kg 1,4-DCB-equivalents	1.88E+11
Acidification	AP	kg SO ₂ -equivalents	6.69E+8
Aquatic eutrophication	AqEP	kg PO ₄ -equivalents	5.02E+8
Terrestrial eutrophication	TerrEP	kg NO ₃ -euivalents	1.13E+9
Biodiversity	BIOD	–	3.08E+12
Life support function	LSF	–	7.41E+10

Biodiversity and life support were adopted as indicators for land use (both occupation and transformation of land). In the NWMP a method developed by IVAM was used [9]. In this particular study an update of this method [10] was used.

In sensitivity analysis some adapted characterization and normalization factors were used. For GWP and the toxicity themes alternative time horizons were used of 500 years and 100 years respectively. For acidification and terrestrial eutrophication a method was introduced which took into account a certain threshold level for these themes. These factors were also derived from the CMLII-guide.

Characterized scores were normalized with normalization factors based on Dutch total scores for 1997.

In the NWMP weighted scores were used for interpretation of the results. In the study for ATM also weighted scores were presented because of compatibility with the NWMP-method is necessary. In this article however only the normalized scores are presented.

4 Results and Discussion

Characterised scores have been calculated with the LCA software SimaPro (version 5.1) and presented as comparable scores with the highest score of the two waste management options put at 100% or -100% in case the avoided burden exceeded the impact score (Fig 2).

The normalisation step provides for a comparison of scores on a similar scale. This exercise gives a good overview of the most prominent LCA-themes (Fig. 3a). This is useful for the interpretation of results and drawing conclusion from this.

The scores for terrestrial ecotoxicity are mainly determined by the emissions of mercury. In the case of the rotary kiln however also emissions of chromium due to leaching from slags are accounted. It is debatable whether this environmental intervention provides a solid foundation for the interpretation of results, given the broadly acknowledged uncertainty of heavy metals assessment in the underlying models in general [12] and the assessment of chromium in particular [8, part 2B, p.131].

In this study the calculation with toxicity potentials taking into account time horizons of 100 years was a standard exercise, as it was in the NWMP. Although a significant improvement of the toxicity themes was found for the rotary kiln option, the scores remained however higher than for the pyrolysis/gasification option.

Indeed only when the leaching of chromium was not accounted, the pyrolysis/gasification option has a worse score for TETP due to a higher emission of mercury to air. Given the dominance of terrestrial ecotoxicity an exercise seemed sensible where this theme is left out. This gives a better transparency of the relevancy of other themes (Fig. 3b).

For most themes the pyrolysis/gasification option seems the more favourable option. The only exceptions are the scores for loss of biodiversity and life support function, both as a result of the land use accounted within the functional unit. In the case of the rotary kiln the better scores are entirely dedicated to avoided production of distilled water.

Relevant themes coming from this exercise are GWP and AP, and to a lesser extent, AD and terrestrial EP.

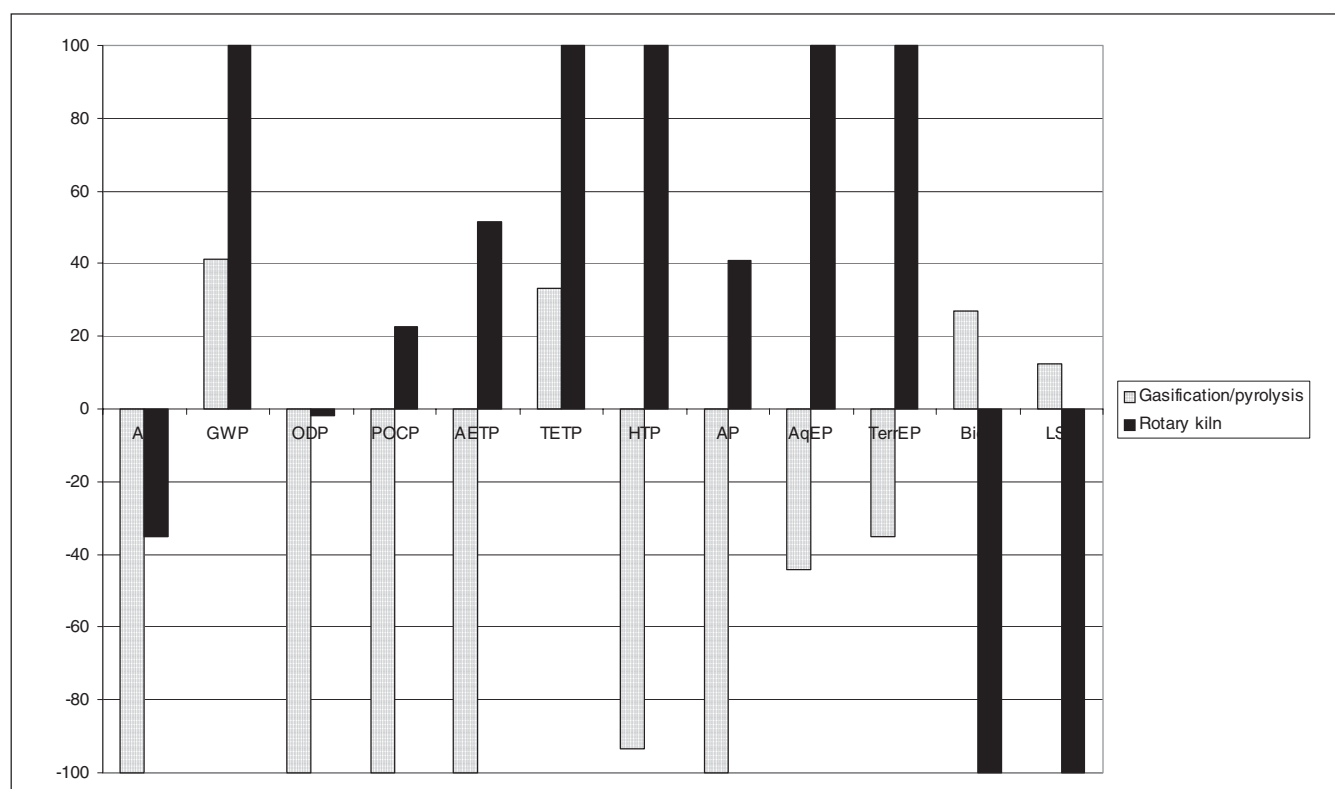


Fig. 2: Characterisation profiles for two waste management options for paint waste

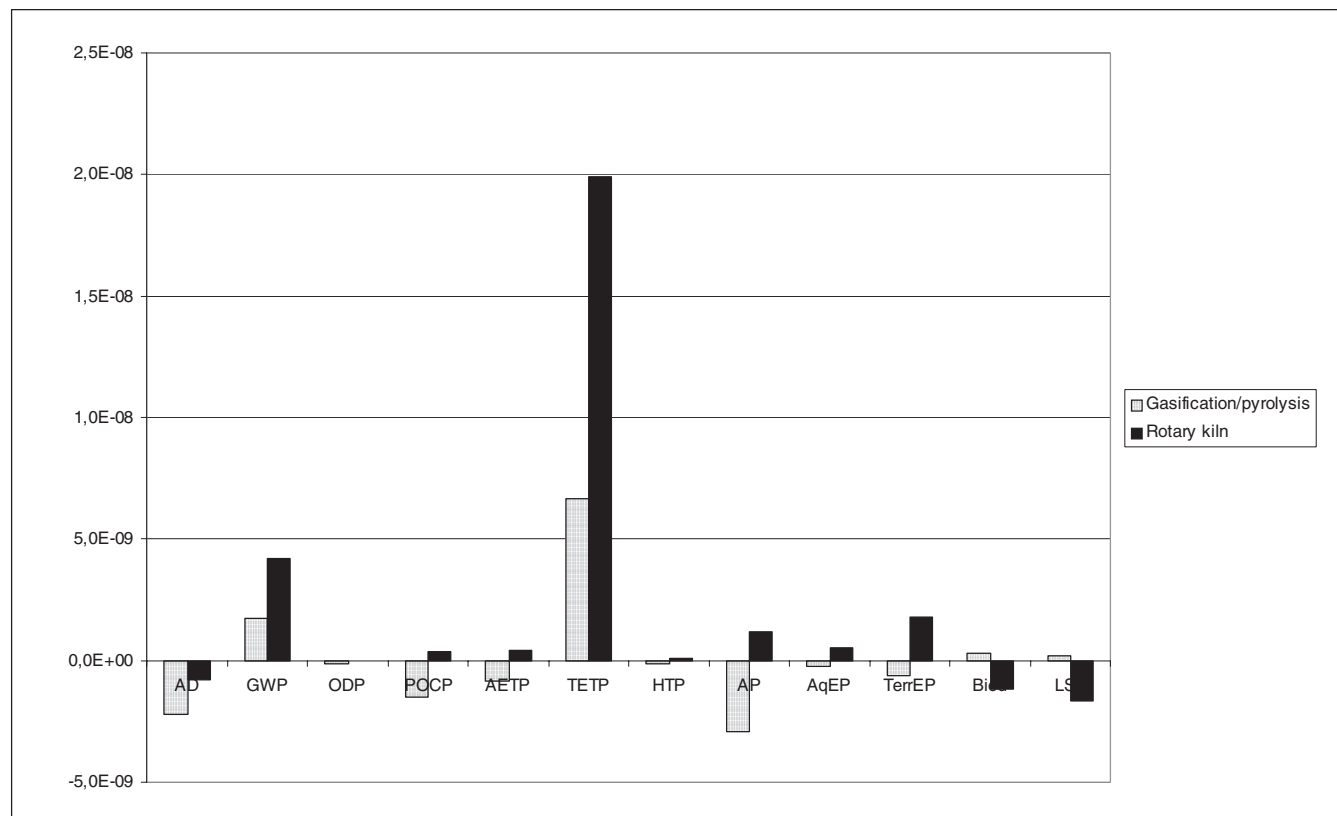


Fig. 3a: Normalised scores for two waste management options for paint waste

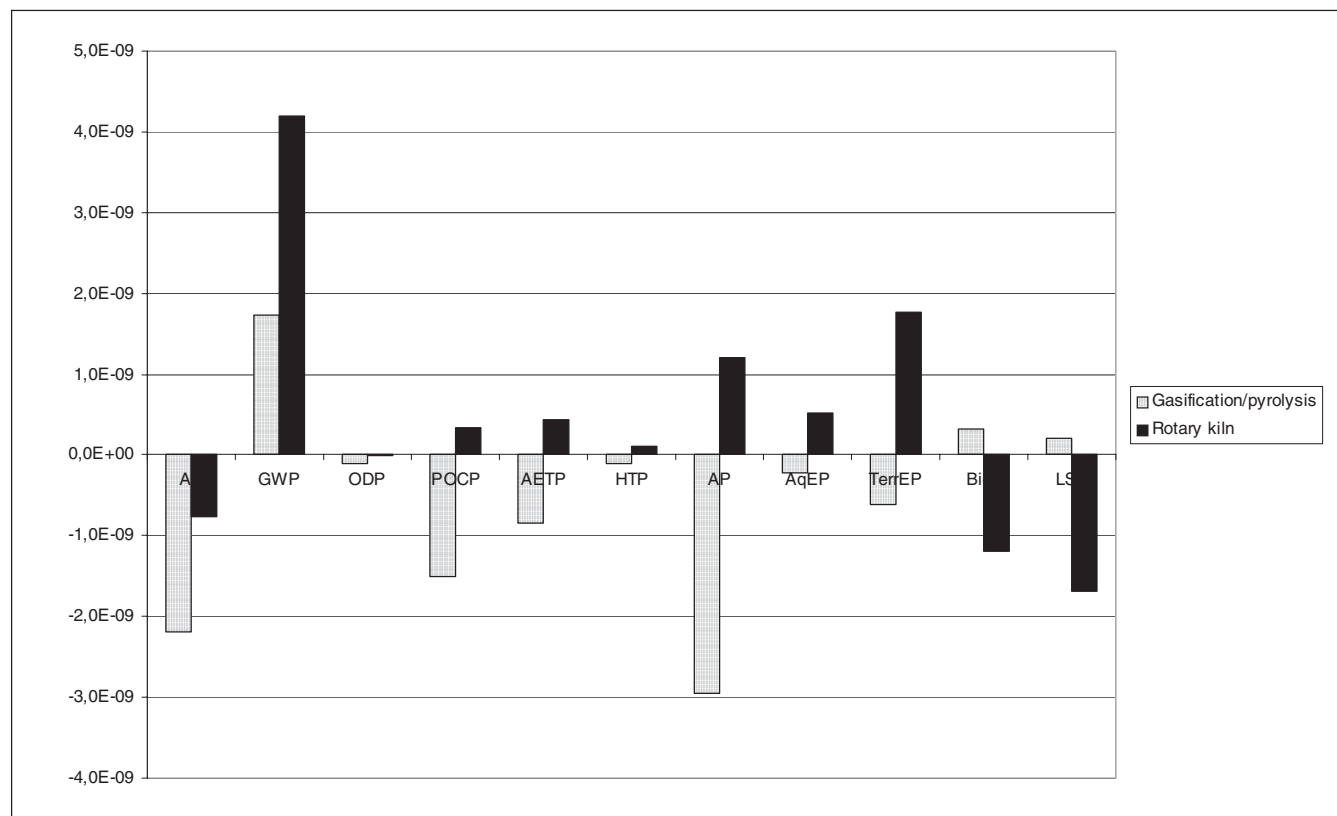


Fig. 3b: Normalised scores for two waste management options for paint waste WITHOUT TETP

GWP is mainly related to fossil CO₂ emissions. The emission of CO₂ for both waste treatment options was calculated from the caloric value of the waste and treated as fossil CO₂. In both options the amounts calculated exceed the emissions from the offset processes. The reason for this in the case of the gasification plant is that the energy savings are hampered by a significant energy consumption coming from the waste shredder, the gasification kiln and the oxygen consumption. In the case of incineration in a rotary kiln the offset of energy is fairly limited to the low energy efficiency of 8–10% in the rotary kiln to produce electricity.

The same consideration is valid for the theme AP (acidification) although here not the CO₂ emission is the relevant parameter but the emission of SO₂.

AD (abiotic depletion) is related to the depletion of fossil fuels mainly. Although the initial depletion of oil and gas is slightly higher for the pyrolysis/gasification option, the avoided burden for the production and use of diesel oil leads to avoided burden overall. In the case of terrestrial EP the emission of NO_x is the most relevant parameter. The rotary kiln option here shows a larger emission anyway, although again the choice for avoided diesel oil in the pyrolysis/gasification option makes the difference even more profound.

A sensitivity analyses showed that neither other assumptions for the calculation of emissions to air and soil nor calculations with a lower energy efficiency of the pyrolysis/gasification option (50% instead of 70%) leads to a picture strongly deviating from the ones presented above.

However, the choice of allocation with avoided burden was made and this decision proved crucial for the outcome of the study. We performed a sensitivity analysis with avoided light fuel oil in stead of the more conservative option of avoided diesel oil and this gave (not surprisingly) an even more favourable outcome for the pyrolysis/gasification option.

The allocation method itself has not been subjected to a sensitivity analysis since one of the objectives of the study was to be compatible with the National Waste Management Plan where the same method (system enlargement) had been applied. A simple method without any allocation (all avoided processes put to zero) showed that the environmental profiles of both options were practically identical, not withstanding the earlier remarks about the leaching of chromium.

5 Conclusions and Recommendations

The study showed that sufficient data were available for both selected waste management options. The rotary kiln is a well known incineration technique providing reliable data on input and output processes. The pyrolysis/gasification option has a shorter track record but has been operational on a stable level for quite a long period now.

The impact assessment showed that for most selected LCA themes the pyrolysis/gasification option has a better environmental score. In the case of TETP the pyrolysis/gasification option seems the less favourable but final conclusions from this should be taken with care due to the dominant emissions of chromium to soil and subsequently the fundamental uncertainty in the derived characterization factors. For the impacts due to land use the rotary kiln scored better.

The outcome of the study is strongly dependant on the choice of an allocation method using system enlargement or avoided environmental burden. In the case of the pyrolysis/gasification option the avoided use of diesel oil as energy carrier for heat leads to avoided environmental burden. It is expected that any other choice of energy carrier (e.g. electricity, light fuel oil) leads to similar or even better outcomes due to the high energy efficiency of the pyrolysis/gasification option.

Another topic for discussion was the calculation of emissions to air. Due to the complex nature of the flue gas cleaning at the pyrolysis/gasification site, several assumptions had to be made here. One of the recommendations to ATM therefore was to establish a better causal relationship between incoming waste streams and outgoing fluxes of substances. In the case of the rotary kiln this is less of a problem since this option is equipped with an own air pollution control system.

Finally the topic of heavy metals and impact assessment was raised (again). It is becoming clear that the underlying models are not suited optimally for the assessment of heavy metals emissions in LCA. In this case the calculated scores due to heavy metals did not affect the overall conclusion. However further research on this topic is important.

Final conclusion from this study was that the environmental profile of the pyrolysis/gasification treatment seems favourable over the rotary kiln or at least not worse. For the environmental permit procedure it is sufficient to prove that the considered waste treatment option has at least an environmental profile which is equal to the minimum standard.

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